SNS* LASER PROFILE MONITOR PROGRESS

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Abstract

SNS will use a Nd:YAG laser to measure transverse profiles in the 186-1000 MeV Super-Conducting LINAC (SCL) and a Ti:Sapphire mode-locked laser to measure longitudinal profiles in the 2.5 MeV Medium Energy Beam Transport (MEBT). The laser beam is scanned across the H- beam to photo-neutralize narrow slices. The liberated electrons are collected to provide a direct measurement of the transverse or longitudinal beam profile. We have successfully measured the transverse profile with a prototype system on the MEBT beam. The final SCL system uses an optical transport line that is installed alongside the 300 meter super-conducting LINAC to deliver laser light at eight locations. Movement of the laser light in the optical transport system can lead to problems with the profile measurement. We will use an active feedback system on a mirror to correct the movements. In this paper we describe our drift and vibration studies and the drift/vibration cancellation system, as well as the progress in the design, installation, and testing of various subsystems for both the transverse and the longitudinal profiles.

INTRODUCTION

The main driving factor for the laser wire is the absence of a wire filament that can break off and migrate to the nearby superconducting surface of the SCL cavities. Such a failure would require time-consuming and expensive repairs. In addition, the laser wire will have no moving parts inside vacuum and can operate at the normal operational beam intensities.

The laser wire operates by using photons to knock off electrons from the H$^-$ ion beam. A magnet directs the electrons to an electron collector was designed to resonate out the 402.5 MHz to achieve a high S/N. The signal of the electrode is digitized as the laser light scans through the H$^-$ ion beam. Plotting the intensity of the electron collector signal versus the scan position results in a representation of the transverse profile, see [1]. A prototype system for the 2.5MeV H- beam at the end of the MEBT was put together in six months to decide whether the laser system was a viable way to replace the planned but not yet built carbon wire system for the SCL, see [2]. The data of the prototype system is shown in Figure 1. The red line, or Gaussian fit, is drawn out to 4.5 times the estimated sigma. The plot shows that the fit matches the profile out to about three sigmas. This is an improvement over using a Beam Current Monitor, which profiles matched the Gaussian out to about one and a half sigma and then showed very noisy tails. Further improvement is expected by correcting for the cable transfer function.

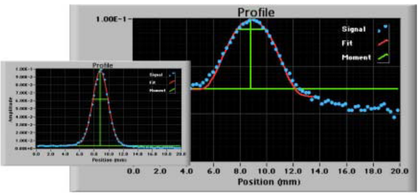

Figure 1. Data from the SCL prototype system plotted logarithmically and linearly (insert).

INSTALLATION PROGRESS

Four-inch diameter stainless steel pipes and 12 optics boxes with mirrors form the laser transfer line shown in Figure 2. We plan to pressurize the transfer line with dry air to about two PSI above atmosphere. Fused silica windows seal the entire laser transport line.

Figure 2. The optical transfer line in the tunnel and beam optics box setup (insert).

The optics boxes (insert in Figure 2) have been fabricated with components installed in 7 out of 8. The pick off boxes (see white arrow in Figure 2) and camera boxes are installed but not all parts have been installed. The flipper mechanism in the pick off boxes has been tested for repeatability. Each optics box (vacuum boxes, actuators, and mirrors), magnet, and electron collector is fitted at a service building.

To prove the long-term survival of the vacuum window in the beam box, it was subjected to 1.5 million pulses at 44 times the required power. This test did not show any damage to the coating or the window. Independent laboratory Big Sky Laser also tested the windows and confirmed that we need 150 MW/Cm^2 to start damaging the window. That is about 80 times the expected power.

DRIFT AND VIBRATION

There are two issues at hand that could affect the laser wire measurements. One issue is that the drift in the opti-

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cal transfer line is so large that the laser beam, which has a diameter of about 2.5 cm at the optics box, will miss a mirror, which has a diameter of about 5 cm. The second issue is the effect of vibrations during a measurement. In case of the transverse profile measurements, the final focusing setup keeps the laser light focused in the same spot no matter where it hits the focusing lens. Given the width of the ion beam, laser beam and the focusing setup even a vibration of several millimeters in the transport line will affect the measurement within 5 percent, see [3]. This means that we have to only worry about aligning the laser light to compensate for drifts.

We have done studies to determine the amount of drift compensation that is needed to get the laser beam through the optical transfer line and accurately at the ion/laser beam interaction point. The drift measurement setup is shown in Figure 3. The drift is measured at about 500 feet of the laser but not quite at the SCL to stay out of the way of LINAC installation work. The laser light shines onto a screen that is monitored with a video camera. A computer with a frame grabber card acquires the video signal at regular intervals. The LabVIEW program takes a histogram of the video data in the horizontal and vertical axis and then fits a Gaussian profile to each histogram. The centroid of the histogram is taken to be the position of the laser beam.

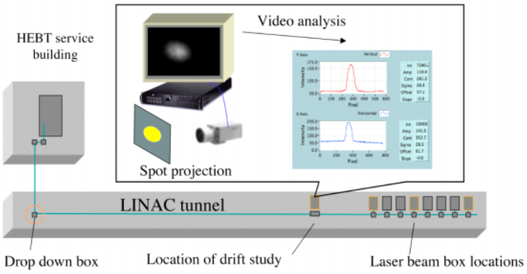

Figure 3. The setup of the laser drift measurement.

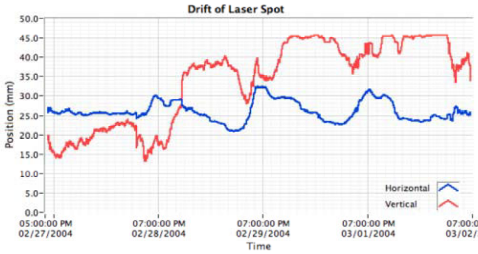

Figure 4. The drift measurements.

The data, see Figure 4, is taken over several days and shows that the maximum beam movement, about 35 mm over 170 m or about 0.2 mrad, is large enough that we need to align the beam for each measurement.

The vibration measurements were done at the same location but with a recently acquired duolateral dual-axis position detector and a PCI digitizer. At the time that both the drift and vibration measurements were made, the laser table hydraulic dampening system was not yet activated, construction was ongoing, and the mounting of the final steering mirror was not yet finalized. Thus we regard the data taken to be worst case. Over a half second the laser spot moved about 1 mm. The spectrum shows vibrations at several frequencies above 10 Hz with 60 Hz having the largest amplitude, about 30μm peak to peak, which is insignificant compared to the contributions of the lower frequencies. Therefore the drift compensation routine should filter out the higher frequencies and correct for only the low frequencies.

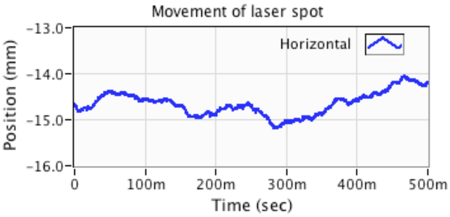

Figure 5. Horizontal position of laser spot over time.

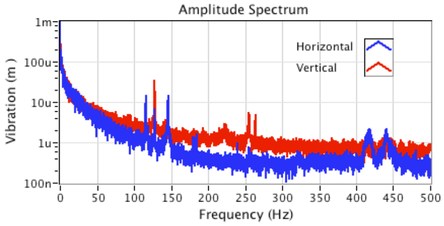

Figure 6. Amplitude (peak to peak) spectrum of the laser spot vibration.

DRIFT COMPENSATION

The test drift compensation system is implemented using a NI PXI FPGA Module with analog inputs and outputs. The waveform generator drives a piezo actuator to move a mirror while a quad detector determines the light's projected position, see Figure 7. The FPGA acquires the signals from the four quadrants and calculates a correction signal that drives the other mirror.

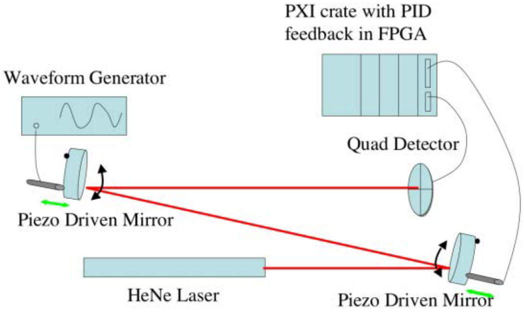

Figure 7. Setup to control drift.

The piezo actuators have a range of 15μm and, given the mirror mount, have an angle of about 0.5 mrad. The drift compensation routine is implemented in LabVIEW FPGA. The FPGA calculates the approximate position of the laser light from the four quads and averages the position results. A PID algorithm from the FPGA library then determines the control signal from the difference between the setpoint and the calculated position. Because the drift frequency is very slow compared to the frequency of the control loop, this simple feedback mechanism works well as shown in Figure 8.

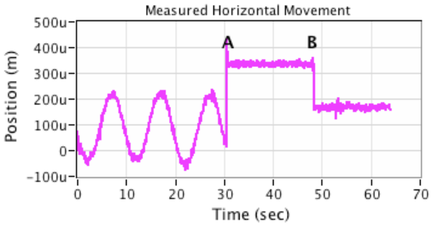

Figure 8. Correction of low frequency drifts.

The motion of about 300 μm at the quad detector is dampened to about 20μm when the feedback loop is turned on at point A or when the setpoint changed at point B. The effectiveness of the feedback loop diminishes with higher frequencies. At around 10 Hz the loop dampens the oscillation to about 80μm. This is well within the requirement of a few millimeters so that the distance from the drop box steering mirror to the quad can be shortened enough or the light focused so that despite the drift the laser will always hit the quad. The next step is to test the feedback system with the actual installation.

We are also considering using a LabVIEW real-time card to implement a more sophisticated vibration feedback loop as the real-time card has a more extensive algorithm library and can use floating point calculations. While the measurements indicate that this is not needed for the transverse profile measurement with the Nd:YAG laser, this might be necessary for the longitudinal measurements with the mode-locked laser.

TI:SAPPHIRE MODE-LOCKED LASER

Intense laser beams can be used not only for measurements of the transverse profiles of the H- beam, but also for a measurement of its temporal profile. Instead of being focused in space, the light, in this case, must be "focused" in time. That is, the laser pulses must be much shorter than the temporal features of the ion beam. With pulse durations of 7-9 ns, the Nd:YAG laser used for the transverse profiles is clearly unsuitable. We are using, instead, a mode-locked Ti:Sapphire laser, which has a tuning range of 700-950 nm. Although such lasers are capable of emitting pulses with durations of only tens of femtoseconds, the 2 ps pulses from our laser are adequate for the features of interest.

As with the transverse laser wire, the laser beam will be directed by mirrors to intercept the ion beam at an angle of 90° in the frame of reference of the ion beam. Lenses will be used to shape the laser beam so that it will: (a) be focused to a small size in the direction of ion beam propagation; and (b) be approximately the same size as the ion beam in the perpendicular dimension. Like the transverse laser wire, the laser pulses here will also be "scanned" across the ion beam. In this case, however, the position of the laser beam will not change. Rather, the relative timing of the laser and ion pulses will be changed so that the laser pulse "scans" through the ion pulse. The laser has been modified so that it operates at a repetition rate of approximately 80.5 MHz and will be locked to the 402.5 MHz LINAC clock. Adjusting the phase of the clock signal implements the scan. Full 3-D interactive computer model of the measuring system including laser focusing, photo-detachment process, propagation and collection of the stripped electrons has been developed and utilized in the design process, see Figure 9.

The laser has been acquired and tested and is located in a room above the MEBT. As with the transverse laser wire, the laser beam will be directed to the ion beam via a series of mirrors. The separation is much smaller, though, so laser beam drift is not expected to be as much of a problem. The hardware for the laser beam transport has been designed and will be installed in time for measurements planned for October 2004.

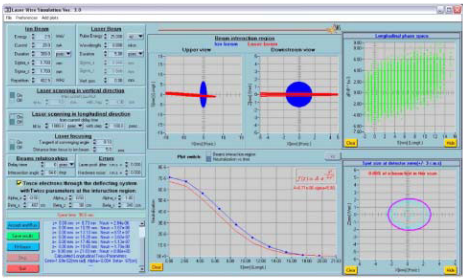

Figure 9. Simulation of the longitudinal measurement.

SUMMARY

The laser profile monitor transfer line is completely designed and installed. The beam optics boxes are manufactured and assembled. We have measured the drift and vibrations of the laser beam. While there is no need to compensate for the vibrations, we must correct for the drift over time to keep the laser light on the mirrors. The implemented feedback loop can correct drifts and low frequency vibrations to about 10 Hz. Our next step is to test the feedback loop in the transfer line. The longitudinal laser measurement instrument is designed, its performance and required electrostatic electron deflector are modeled. The schedule calls to have a longitudinal profile measured by October 2004.

ACKNOWLEDGEMENTS

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